Investigation of Plastic Encapsulated Microcircuits (PEMs) used in Low Earth Orbit Nano-Satellites\[1\][2]

Laboratory of Plasma Laser and Computational Engineering (Cho Laboratory)
Student Number: 13350946 Name: Chen Shiyi Danny

Introduction With the proliferation of nano-satellites being adopted for space missions by commercial companies and educational institutions, the use of commercially off the shelf (COTS) components for space applications has escalated unprecedentedly. The driving forces for their usages include lower costs, shorter lead time and availability etc. Different from hermetically sealed and radiation hardened components, these COTS-based PEMs are not rated for operations in the harsh space environment. Typically, nano-satellites (<10 kg class) are launched to low earth orbits (<1000 km altitude). A nano-satellite in low earth orbit may be irradiated with an average of \(-11.8\times10^{-14}\) Am\(^2\) (7.39\times10^5 electrons m\(^{-2}\)s\(^{-1}\)) from electrons with energy higher than 500 keV. These high energy electrons are sufficiently energetic to penetrate the thin aluminum exterior panels (typically 1 mm) of nano-satellite to reach the interior electronics. The suitability and capability of PEMs to be used in aerospace and military applications had been evaluated in great depth \[3\]. However, the lack of long term operating reliability data for space applications and inadequacy of industry standard reliability/quality assurance procedures, makes it a legitimate concern to characterize in greater detail the properties of COTS-based PEMs.

Purpose Research is conducted to determine if internal charging and electrostatic discharge (IESD) may occur to PEMs used in nano-satellites. Measurements pertaining to the charging and discharging phenomenon shall be recorded and derived. Methods used to mitigate charge accumulation shall also be explored.

Experiment 1 PEMs samples were mounted on FR4 substrate and placed in a vacuum chamber. Irradiation of high energetic electrons will induce discharges caused by breakdown of electric field as differential charging takes place between dissimilar materials. After irradiation, the samples were allowed to relax and their surface potentials were measured at regular intervals using a non-contact voltmeter.

Results From conducting the electron beam test for resistivity outlined in NASA-HDBK-4002 \[4\], the average time constant for charge decay was 27.5 hours corresponding to a resistivity value of \(3.19\times10^{15}\)\(\Omega\text{m}\). Discharges were captured on an infra-red camera.

\begin{table}[h]
\begin{tabular}{|c|c|c|c|c|}
\hline
Sample type & Ave. time constant & Max. time constant & Min. time constant & No. of samples \\
\hline
40-Pin PDIP & 1223 mins & 1549 mins & 841 mins & 15 \\
SOIC 28 & 1828 mins & 8726 mins & 526 mins & 36 \\
\hline
Sample type & Ave. resistivity \(\Omega\text{m}\) & Max. resistivity \(\Omega\text{m}\) & Min. resistivity \(\Omega\text{m}\) & No. of samples \\
\hline
40-Pin PDIP & \(2.37\times10^{15}\) & \(3.5\times10^{15}\) & \(1.42\times10^{15}\) & 15 \\
SOIC 28 & \(3.54\times10^{15}\) & \(1.97\times10^{16}\) & \(8.91\times10^{14}\) & 36 \\
\hline
Overall & \(3.19\times10^{15}\) & \(1.97\times10^{16}\) & \(8.91\times10^{14}\) & 51 \\
\hline
\end{tabular}
\end{table}

Graph 2: Decay of surface potential of samples 1 day after irradiation of 10keV electrons (top) Table 1: Table summary of all results from electron beam test (left)
**Simulations** SPENVIS runs the AE8 model over a spacecraft trajectory defined in the orbit generator segment. The trapped electron radiation environment was generated at altitude between 400km to 1000km to find out the average and peak electron current density in LEO. The Monte Carlo simulation of electron penetration trajectory simulate the trajectory of high energetic electrons as it hits the surface, deposits and translates through aluminum.

**Results** Combining the simulation results from Space Environment Information System and Monte Carlo Simulation for Electron Penetration Trajectory, we obtained the conditions of transmitted electrons and internal electric field conditions based on the full energy spectrum of electrons in LEO.

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>400</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric field expected for average internal electron current density ((10^7 \text{V/m}))</td>
<td>0.053</td>
<td>0.075</td>
<td>0.098</td>
<td>0.125</td>
<td>0.155</td>
<td>0.189</td>
<td>0.216</td>
</tr>
<tr>
<td>Electric field expected for worst internal electron current density ((10^7 \text{V/m}))</td>
<td>2.22</td>
<td>2.34</td>
<td>2.79</td>
<td>3.13</td>
<td>3.19</td>
<td>3.71</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Table 2: Maximum electric field expected on PEM circuit inside a nanosatellite enclosed by 1mm thick aluminium

**Conclusion** With the findings of this investigation, the author has confirmed that the molding material used for PEMs packaging is susceptible to internal charging from energetic electrons that will penetrate into the insides of LEO nanosatellites. If left unattended, the charges will slowly build up till the point where the threshold voltage is reached. As the electric field exceeds the breakdown field, an IESD may occur causing catastrophic damage to itself or nearby components. Long term effect of electron irradiation does not alter the resistivity of the molding compound for PEMs. Next, simulations the space environment of LEO at different altitude to find out the composition of high energy electrons that a nano-satellite may encounter in space. The penetration path trajectories of these high energy electrons were simulated so as to determine the final magnitude of current density in the interior of nano-satellites with 1mm thickness of aluminium chassis. Based on both experimental and simulation results, calculations proved that internal electronics will charge to a point of discharge unless mitigation methods are utilized. Conformal coating a printed circuit board was proven to be effective in the mitigation of internal charging.

**Future Work** The author recommends electron irradiation of actual satellite hardware, printed circuit boards etc, to observe how the geometry and placement of PEMs may affect the likelihood of internal charging and eventual IESD. In addition, other internal charging and IESD mitigation methods such as tungsten shield, electron emitter and plasma contractor should be explored to determine their effectiveness. Radiation induced conductivity can be explored to find out in greater detail the long term effect of electron irradiation has on PEMs. Lastly, experiment setup can be improved by using a high energy, >50keV, multi spectrum electron source. With this improvement, buried charges in dielectric material can be investigated.